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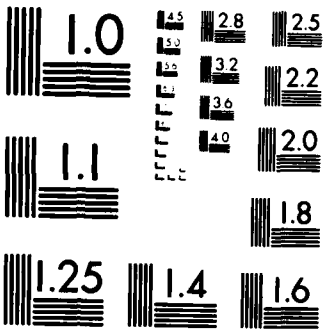

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NAVY EXPERIMENTAL DIVING UNIT
REPORT NO. 12-84

EVALUATION OF HAND-HELD CO_2 DETECTORS

By:

E. F. Downs. Jr.

NAVY EXPERIMENTAL DIVING UNIT

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

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NEDU evaluated the Draeger and Matheson-Kitagawa hand-held CO_2 detector under a variety of depths and CO_2 concentrations during a 1000 FSW saturation dive. The Draeger, currently available through standard stock, proved to be best suited for chamber CO_2 analysis.

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ABSTRACT

CO_2 build up in recompression chambers has for the most part been an unmeasured hazard. Frequent venting has provided a degree of safety, although again unquantified.

NEDU evaluated the Draeger and Matheson-Kitagawa hand-held CO_2 detector under a variety of depths and CO_2 concentrations during a 1000 FSW saturation dive. The Draeger, currently available through standard stock, proved to be best suited for chamber CO_2 analysis.

KEY WORDS:
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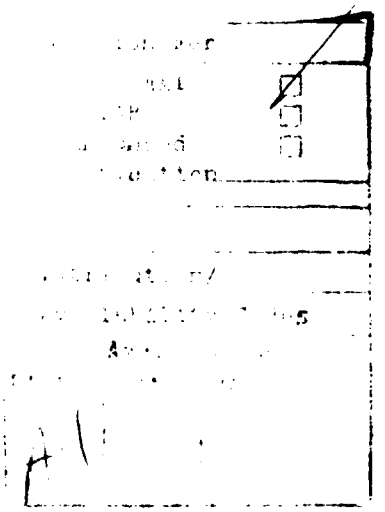
Draeger
MSA
Matheson-Kitagawa
Bendix
CO_2 Analysis



INTRODUCTION

Currently, the 100 psi double lock recompression chambers in the Fleet have no method of monitoring or removing Carbon Dioxide (CO_2) from the chamber atmosphere. The ability to accurately monitor chamber CO_2 would offer a method of insuring that chamber CO_2 level did not exceed 1.5% (11.4 mmHg) as set forth in the U.S. Navy Diving Manual.

Industry has many methods of monitoring CO_2, but there are considerations that must be addressed, such as: cost; ease of use; maintenance; reliability; accuracy; durability; and portability. With these ideas in mind, the choice of CO_2 analyzers narrows considerably. The analyzers which appear best suited for use in monitoring chamber CO_2 levels are the chemical stain tube type. The stain tubes are inexpensive, simple to use, require no calibration gases as do other CO_2 analyzers and have a relatively long shelf life. The stain tubes available commercially are Draeger, Mine Safety Appliance (MSA), Matheson-Kitagawa and Bendix. The Draeger is also currently available in the Federal Stock System. The stock number for the Draeger pump only is 1H6665-00-710-7815; the tubes used in this report are .1 to 6% CO_2, stock number 1H6665-00-769-0945. Of these four CO_2 detectors, MSA, Matheson-Kitagawa and Bendix employ a piston type hand pump whereas the Draeger uses a small hand-held bellows. This study describes testing of the Draeger hand-held bellows unit and a typical representative of the Piston type pumps, the Matheson-Kitagawa. The object of the test was to find a sampling apparatus which would work both inside and outside of a hyperbaric chamber.

METHODS

Performing the tests in an air dive was not possible, so the tests were carried out during a helium saturation dive held in the Ocean Simulation Facility (OSF) in accordance with NEDU Test Plan #83-60. Since gas density is the most significant variable affecting the detectors' ability to function properly, the tests were conducted at three depths: 650 FSW, 486 FSW, and 200 FSW. These correspond to 70 FSW, 60 FSW and 10 FSW equivalent air density depths respectively.

The range of gas measured was also of interest, since the Draeger tube has two sensitivities and the Matheson-Kitagawa only one. Chamber tests were set up to measure chamber CO_2 levels of approximately 0.5% SEV and diver exhaled CO_2 levels of approximately 5% SEV. Diver exhaled gas provided a convenient source of high level CO_2 without the need to have a bottle of calibration gas inside of the chamber. This also provided a sufficient range to evaluate the linearity of the detector tubes.

The chamber gas was analyzed by having the diver draw a sample from the chamber atmosphere. To measure diver exhaled gas, a Gas Collection Bag (GCB) (See Figure 2) designed for use with stain tubes was used. The same type collection bag was used for executing the tests at the surface. The actual CO_2 concentration of the gas samples in the chamber and the collection bags

were analyzed by a modified MGA 1100 Perkin-Elmer Mass Spectrometer located outside the chamber. The Mass Spectrometer resolution is ± 50 ppm CO_2. The data from the mass spectrometer was recorded on a Gould Mark 200 Strip Chart Recorder. Calibration of the mass spectrometer was performed immediately prior to and following each test.

Draeger Pump Kit Test

Three tests were conducted at each depth using the Draeger pump shown in Figure 1. The first used the pump inside the chamber to sample chamber CO_2; the second used the pump inside the chamber to sample diver's exhaled gas which was blown into a Gas Collection Bag; the third used the pump outside the chamber to measure the same diver exhaled gas used in the second experiment which had been routed to the surface through a sample line.

Before each experiment the Draeger pump was tested for leaks by inserting an unopened tube into the pump, squeezing and releasing the pump, and watching for any expansion. This is essential to insure the integrity of the measurement. Next, the sample tube tips are broken off and the tube is inserted into the pump. The CO_2 tubes used in the study have two scales printed on the tube; one ranging from .1 to 1.2% and the other .5 to 6%. The .1 to 1.2% scale is read when the pump is squeezed and released five times. The .5 to 6% scale is used when the pump is squeezed and released one time. After the sampling is complete, a chemical reaction between CO_2 and the detector tube reagent causes a blue-violet color change to occur inside the tube. The total length of discoloration is a measure of CO_2 concentration. The percent of CO_2 is read from the graduation printed on the tube at the point when the blue-violet color ends. While performing the tests, the total time it took the bellows to fully expand for each sample tube was recorded.

A total of three separate sample tubes were used in each test. Three subjects read each of the three tubes, always starting with tube #1 and ending with tube #3. Each subject recorded his reading on a preprinted form without revealing his reading to the other subjects. This prevented any biased readings. These were later compared with the mass spectrometer readings.

The first experiment was analysis of ambient chamber CO_2 levels. Since the chamber CO_2 levels are maintained below 3.8 mmHg (.5% Surface Equivalent), this mandated the use of the .1 to 1.2% scale. The preparations of the Draeger pump were carried out prior to each tube test as stated previously. The mass spectrometer sample line was placed near the openings of the Draeger tube to allow constant monitoring of the chamber CO_2 level. The total tube sample time was noted and recorded for each test. Upon the completion of three sample tubes, the tube readings were recorded by these test subjects.

For the second experiment, a diver blew into the gas collection bag after thoroughly purging it with 100% helium to remove any residual CO_2. The Draeger pump and sample tube were prepared and the gas collection bag adaptor needle placed on the end of the Draeger tube. The exhaled gas (CO_2) provided CO_2 levels of approximately 3% to 5% Surface Equivalent at each depth. The expansion time of the bellows was measured and the .5-6% scale was used,

requiring only one pump per sample tube. The process was repeated three times and recorded in the same manner by the same three subjects in the first Draeger experiment. Analysis of the GCB sample by the mass spectrometer was performed by placing the sample line used in the first experiment into the GCB.

The third Draeger experiment was conducted at 1 ATA on the Medical Deck of the OSF, immediately following the second Draeger test. In this study, gas from the GCB inside of the chamber was routed through a small bore sample line into a second GCB outside of the chamber. The Draeger pump was used to sample gas from this GCB using the .1 to 1.2% scale since the actual CO_2 ranged from .19 to .6%, depending on the depth. Three sample tubes were used and the sample time recorded for each as was done in the previous tests. The tube readings were recorded separately by three subjects in the same manner as the chamber tests. The sample in the second GCB was again anlayzed using the mass spectrometer at the end of the test to insure there was no change.

Matheson-Kitagawa Test

The Matheson-Kitagawa, Figure 3, was set up to test the chamber CO_2 in the same manner as the Draeger. The factory leak check procedure was attempted prior to each experiment by inserting an unopened tube into the pump end and pulling the piston handle out until fully extended and waiting 2 minutes.

The above procedure was attempted at the same depths as and immediately following the Draeger chamber tests. The divers were not able to pull the piston handle for a leak check at any of the test depths due to the increased gas incompressibility at depth. The experiment was terminated at this point. (See Discussion).

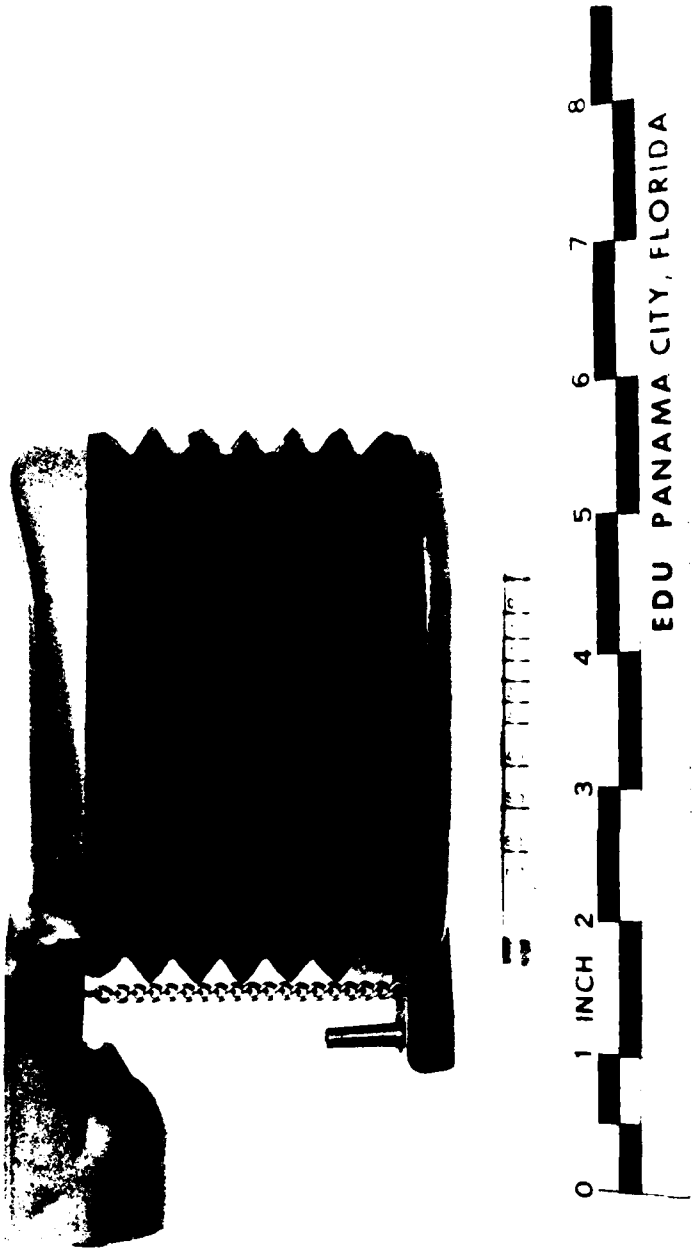


FIGURE 1

DRAEGER PUMP AND SAMPLE TUBE

FIGURE 2

GAS COLLECTION BAG (GCB) WITH ADAPTOR NEEDLE

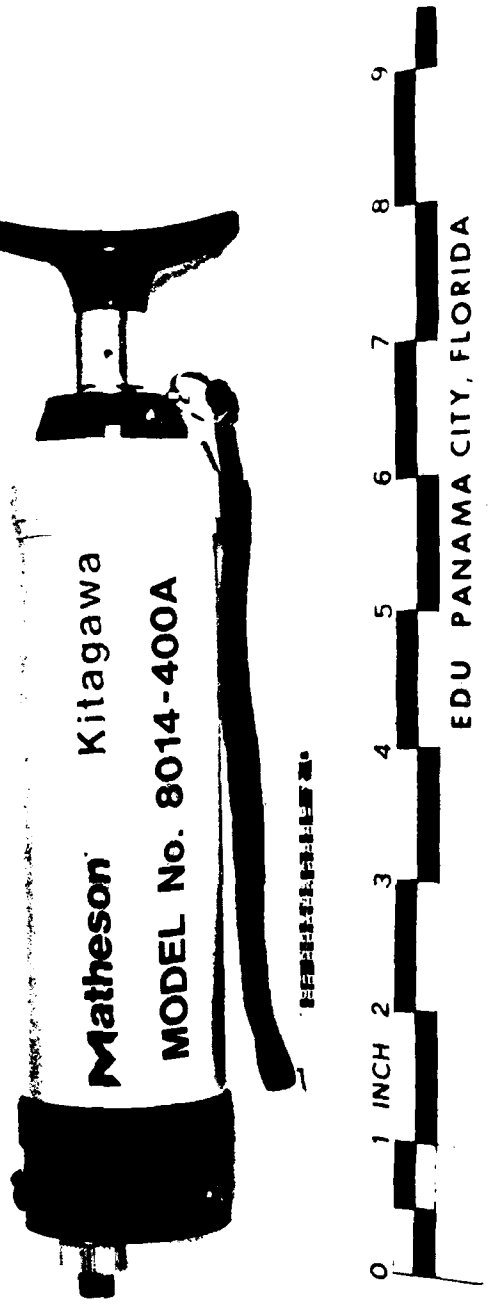


FIGURE 3

MATHESON-KITAGAWA PUMP AND SAMPLE TUBE

RESULTS

The results of Draeger tube tests are presented in Tables 1-3.

The CO_2 tubes used in this experiment have built-in systematic errors, for which they should be corrected. These errors are due to a number of reasons: properties of the chemical reagent in the tube change during storage, pump does not pull exactly the calibrated amount of sample (100 cc per stroke); bellows does not have full suction capacity; subjects reading the tubes will not all record the same values. The results of multiple tube samples, however, will all fluctuate around a mean value. This variance has been determined by Draeger to depend on where the discoloration is in the tube. This variance will be different for different range tubes.

For the CO_2 tubes used in this experiment, the variance supplied by the manufacturer are listed below:

.1 to 1.2% Scale

Variance = ± 10% of reading from 0 to .30%
Variance = ± 5% of reading from .30 to 1.2%

.5 to 6% Scale

Variance = ± 10% of reading from 0 to 1.5%
Variance = ± 5% of reading from 1.5 to 6%

The average sample time for the chamber test is much shorter than that of either the Draeger bag sample in the chamber or at the surface. This is due to the fact that a small bore adaptor needle is placed over the end of the Draeger tube so that the needle can be inserted into the GCB to take the sample. This greatly increases the sample time but does not affect the tubes' accuracy.

Matheson-Kitagawa

The Kitagawa piston pump could not be pulled back at <u>any</u> of the test depths. Three divers tried to pull the pump without a tube inserted. Due to the piston pump design, they cannot be used in a hyperbaric environment since they cannot be pulled.

TABLE 1

DRAEGER CHAMBER TEST (650 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Readings	Mass Spectrometer Reading Converted to SEV%
1	.26% ± .03%	.26%
2	.32% ± .03%	.24%
3	.29% ± .03%	.24%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 5 PULLS = 97 sec

DRAEGER CHAMBER BAG SAMPLE (650 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Readings	Mass Spectrometer Reading Converted to SEV%
1	4.03% ± .20%	3.81%
2	4.03% ± .20%	3.81%
3	3.90% ± .03%	3.81%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 1 PULL = 54 sec

DRAEGER GBC (GAS FROM 650 FSW SAMPLED AT SURFACE)

CO_2 level was below the detection capability of the .1 to 1.2% Detector Tube.

TABLE 2

DRAEGER CHAMBER TEST (486 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	.32% ± .02%	.21%
2	.30% ± .02%	.21%
3	.29% ± .02%	.21%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 5 PULLS = 93 sec

DRAEGER CHAMBER GCB SAMPLE (486 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	4.2% ± .21%	3.95%
2	4.2% ± .21%	3.95%
3	4.3% ± .22%	3.85%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 1 PULL = 51 sec

DRAEGER GCB (GAS FROM 486 FSW SAMPLED AT SURFACE)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	.20% ± .02%	.24%
2	.19% ± .02%	.24%
3	.18% ± .02%	.24%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 5 PULLS = 165 sec

TABLE 3

DRAEGER CHAMBER TEST (200 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	.30% ± .03%	.23%
2	.30% ± .03%	.21%
3	.32% ± .03%	.18%

AVERAGE SAMPLE TIME PER TUBE REQURING 5 PULLS = 87 sec

DRAEGER CHAMBER GCB SAMPLE (200 FSW)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	5.2% ± .26%	4.86%
2	5.2% ± .26%	4.86%
3	5.39% ± .27%	4.96%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 1 PULL = 37 sec

DRAEGER GCB (GAS FROM 200 FSW SAMPLED AT SURFACE)

Tube #	Mean ± s.d. of 3 Independent Tube Reading	Mass Spectrometer Reading Converted to SEV%
1	.63% ± .03%	.69%
2	.63% ± .03%	.69%
3	.60% ± .03%	.69%

AVERAGE SAMPLE TIME PER TUBE REQUIRING 5 PULLS = 144 sec

DISCUSSION

CO_2 Stain tubes are all similar in construction and operation. The tubes consist of a chemical reagent inside a sealed glass cylindrical tube. To use a tube, the operator breaks off both ends and inserts it into the hand-held pump. The gas sample is then drawn into the tube by using the hand-held pump. As the CO_2 enters the tube, a chemical reaction takes place causing the reagent to change color. The length of color change inside the tube is directly proportional to the CO_2 concentration. The exact value of CO_2 is read from a scale printed directly on the tube. As stated previously, the tubes are basically the same with the exception of tube diameter and length.

The hand-held pumps are similar for the MSA, Matheson and Bendix. All are a piston pump type. To admit the sample into the tube, the operator inserts a prepared tube into the end of the pump and pulls the plunger out to the predetermined mark. A small orifice inside the pump allows a constant calibrated sample rate to flow through the tube.

The Draeger pump is a bellows type. The bellows is small enough to be depressed and released with one hand. To use the Draeger, the operator inserts a prepared tube into the Draeger pump, squeezes and releases. The bellows expands drawing the sample through the detector tube. The tube changes color and is read in the same manner as mentioned above.

As mentioned previously, the stain tubes are read in percent by volume CO_2 when used at 1 atmosphere of pressure (1 ATA). However, the tubes are read in surface equivalent percent when used in a hyperbaric environment. What this means is that if a diver on air is at 33 FSW (2 ATA), the gas density is exactly doubled, and there are twice the number of gas molecules in 1 liter at 2 ATA as opposed to 1 liter at 1 ATA. For example, if the atmosphere contained .5% CO_2 by volume at 1 ATA and the chamber was taken to 2 ATA; assuming the chamber CO_2 was maintained at .5% by volume, if a Draeger sample were taken inside the chamber the tube would read 1% CO_2; however, if the same chamber gas were analyzed using a GCB outside the chamber, the Draeger would indicate the CO_2 value to be .5% by volume. This is due to the fact that stain tubes react with the number of CO_2 molecules introduced into the tube. This has an advantage for the diver when used inside the chamber since the diver does not need to know what the high CO_2 percent by volume values are for each depth. He simply reads the tube directly in surface equivalent percent.

Current Navy standards recommend that chambers with a CO_2 scrubber system must have the canister replaced when the mixed chamber CO_2 level reaches 1.5% SEV, whereas chambers without CO_2 removal equipment must constantly be vented to keep the CO_2 level below 1.5% SEV. The Draeger was tested and found to be well within manufacturer's variance specifications (see Results). This accuracy is acceptable for measuring CO_2 levels in both of the above conditions. The preferred method of CO_2 measurement is to carry out the measurement inside the chamber. This is due to the fact that a tube reading

from .5 to 1.5% will fall in the upper 75% of the tube where the variance is ± 5%. The same chamber analysis, when conducted at 1 ATA, will fall on the lower 25% of the tube where the measurement variance is ± 10%. However, with a variance of ± 10%, the Draeger tube will still provide a sufficiently accurate CO_2 analysis.

Draeger Tube Advantage/Disadvantage

The Draeger sampling is somewhat faster in the chamber as opposed to the surface (see Results), but no accuracy appears to be lost in measurement. According to the manufacturer, temperature does not affect Draeger tubes so long as the measurement is made between 0° and +86°F. Above 86°F, the reading is +25% of that value indicated on the tube. Humidity has no effect on the readings. The Draeger pump kit is simple to operate, inexpensive, has a relatively long shelf life and is reliable.

According to the manufacturer, no gas other than CO_2 affects the Draeger tube reading. The shelf life of the detector tubes is 2 years. This time is started when the tube is manufactured. The user has two years from the date stamped on each box to use the tubes. The tubes used in our experiment were obtained from the Federal Supply System and had 13 months remaining to be used.

MATHESON-KITAGAWA ADVANTAGES/DISADVANTAGES

Conversation with U.S. Navy saturation divers revealed that piston pumps have been used in hyperbaric environments in the Fleet; however, the men had to tie the pump to the overhead and hang all their weight on the piston shaft in order tc get the piston to move. This method is totally unacceptable for normal U.S. Navy use. The above information precludes any further explanation concerning Kitagawa specifications.

CONCLUSIONS

The fact that the piston pump CO_2 detector cannot be operated in a hyperbaric environment eliminates it from consideration for use in and around a 100 psi recompression chamber. This leaves the Draeger hand-held bellows sampling apparatus which has been demonstrated to have sufficient accuracy both at depth and on the surface, as the only one acceptable for use with a hyperbaric chamber.

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